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REPLY TO
ATTENTION OF

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Environmental Effects of Dredging
Technical Note
EEDP-01-15 (May 1989)

BIOACCUMULATION OF CHLORINATED CONTAMINANTS AND CONCOMITANT SUBLETHAL EFFECTS IN MARINE ANIMALS: AN ASSESSMENT OF THE CURRENT LITERATURE

Technical Note EEDP-01-15 (May 1989) was published without the complete References listing. It has been reprinted to correct this error; please discard your other copy.

EEDP-01-15
May 1989

Environmental Effects of Dredging Technical Notes

BIOACCUMULATION OF CHLORINATED CONTAMINANTS AND CONCOMITANT SUBLETHAL EFFECTS IN MARINE ANIMALS: AN ASSESSMENT OF THE CURRENT LITERATURE

PURPOSE: This note focuses on studies evaluating the sublethal effects of chlorinated organic contaminants on marine and estuarine organisms. Its objective is twofold: (1) to survey the literature for papers reporting both the sublethal effects of organohalogens and the corresponding body burdens in marine fish and invertebrates and (2) to provide a source of information for Corps field elements who have site-specific concerns (e.g., reproductive effects in a particular organism exposed to a specific organohalogen).

BACKGROUND: The US Army Corps of Engineers has the responsibility to ensure that contaminated sediments are dredged and disposed of in a manner that will not have an unacceptable adverse impact on the environment. The aquatic disposal of dredged material is regulated under two Federal statutes: Section 404(b)(1) of the Federal Water Pollution Control Act, as amended (PL 92-500) and Section 103 of the Marine Protection, Research, and Sanctuaries Act, as amended (PL 92-532). The regulations implementing these laws often require an evaluation of sediment toxicity and bioaccumulation potential prior to dredging and aquatic disposal.

Approximately 370 million cu m of sediments are dredged every year in the United States (Engler 1980). Approximately half of that volume is placed in open water. In most instances, dredged material is not acutely toxic to aquatic organisms. Therefore, decision-makers have had to rely less on toxicity data and more heavily on the results of bioaccumulation tests to evaluate potential impacts on the environment. There is very little interpretive guidance to assist in this evaluation (Peddicord and Hansen 1983). This report, produced under Work Unit 31773, Environmental Interpretation of Consequences from Bioaccumulation, of the Long-term Effects of Dredging Operations (LEDO) Program was designed, in part, to help provide that interpretive guidance.

ADDITIONAL INFORMATION: Contact one of the authors, Ms. Alfreda B. Gibson, (601) 634-4027, or Dr. Thomas M. Dillon (601) 634-3922, or the manager of the Environmental Effects of Dredging Programs, Dr. Robert M. Engler, (601) 634-3624.

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Approach

A literature search was performed for information on the sublethal effects of organohalogenated contaminants on marine and estuarine animals. Only those investigations which examined organismic endpoints (growth, reproduction, behavior, morphology, osmoregulation, and metabolism) were considered. The reasons for evaluating organismic sublethal endpoints are discussed in Dillon (1984). The scope of this literature review was large. More than 50 technical journals were individually reviewed (Table 1). Ten data base literature search services were also used to identify any additional papers (Table 1).

For every paper included in this review, the following information was recorded: contaminant, test animal, exposure time, contaminant exposure concentration, reported tissue concentration, and any observed biological effects. The test animal was identified by common name and/or phylogenetic group. Tissue concentrations were expressed on a wet-weight basis. Exposure concentrations were all reported as micrograms per litre (parts per billion) unless noted otherwise.

Analysis

Approximately 1,200 published papers reporting the sublethal effects of chlorinated contaminants on marine and estuarine animals were identified in the literature. Of these, only 37 papers (3 percent) contained both sublethal effects data and contaminant tissue concentrations (Table 2).

Growth and behavior were the most frequently examined sublethal endpoints, while metabolism and osmoregulation were the least examined. Effects on reproduction and morphology appeared to be intermediate choices. The test organisms used by most investigators were fish and arthropods. They appeared in 51 percent and 36 percent of the papers, respectively. The environmental contaminants most frequently tested were kepone (30 percent) and polychlorinated biphenyls (PCBs) (24 percent). Exposure to contaminants was mainly via aqueous solutions (73 percent) or food (27 percent). None of the residue-effects papers involved contaminated sediment.

Because only 3 percent of the sublethal effects investigations considered published concomitant tissue residue information, the data base for

establishing quantitative residue-effects relationships is very limited. Variations due to interspecific differences, exposure regimes, and analytical capabilities diminish the ability to generate quantitative contaminant-specific guidance. However, a very broad generalization can be made based on data contained in Table 2. For marine and estuarine organisms with whole body tissue residues of chlorinated organic contaminants at or near steady-state, the level of concern associated with potential adverse sublethal effects is:

LOW for tissue concentrations <0.1 µg/g wet weight
MEDIUM for tissue concentrations 0.1-1.0 µg/g wet weight
HIGH for tissue concentrations >1.0 µg/g wet weight

These are not discrete thresholds, pass-fail values, or numerical criteria. Rather they are heuristic and are the only general guidance the data will allow.

Discussion

This review and assessment of the literature has shown that few laboratory investigations (3 percent) report both sublethal effects of chlorinated organic contaminants and tissue residue data. In an earlier review which included biochemical and cellular endpoints as well as organismic responses (Dillon 1984), a similar frequency of residue-effects in the published literature was noted (6 percent). This paucity of residue-effects information hampers the ability to generate contaminant-specific guidance for interpreting results of bioaccumulation tests. This does not mean, however, that evaluative techniques are nonexistent. There are several.

It is often desirable to make relative comparisons among bioaccumulation data rather than to infer specific effects from absolute tissue concentrations. For example, bioassay data from a specific project sediment can be compared to a reference value. This reference value may be generated in the laboratory by exposing bioassay organisms to sediment collected at or near the aquatic disposal site. The resultant tissue concentration is then the comparative standard. Exposure to reference sediment is carried out concurrently with project sediment bioassays. A reference value may also emerge from a consensus process in which tissue concentrations, representing indigenous

organisms in a spatially discrete area, are identified (e.g., New York District matrix values). In both instances, bioassay results are interpreted from the standpoint of "no further degradation." It is important to note that although statistically significant differences may be observed in the laboratory, they do not necessarily imply that unacceptable adverse impacts in the environment are imminent or even inevitable.

In addition to ecological effects, tissue residue data may be interpreted in terms of human health issues. This can be done directly when the bioassay organism (or appropriate surrogate) is one commonly ingested by man. Numerical guidance for assessing contaminated seafood has been developed by agencies such as the US Food and Drug Administration and the Australian National Health and Medical Research Council. A summary of these data can be found in Peddicord et al. (1986). Local guidance in the form of action levels for seafood may also be available from state officials and US Environmental Protection Agency (USEPA) Regional Offices. If the bioassay does not involve an organism normally consumed by man, human health impacts can still be evaluated, albeit in a more circuitous manner. This is done by examining the potential for trophic transfer in the marine food web. Transfer may include the phenomenon of biomagnification, but this process is not common for many contaminants when trophic levels are strictly aquatic (Kay 1984). Biomagnification can become very important quantitatively when the trophic transfer process exits the aquatic environment. An in-depth technical discussion of this subject can be found in Biddinger and Gloss (1984).

When interpreting bioassay results, one must assess not only individual contaminants but also the impacts of multiple contaminants within the same tissue matrix. The first step in this analysis is, "How many and how much?" This approach can be quite useful in initial evaluations. For example, one would be very concerned if 10 out of 12 compounds were taken up in substantial amounts. The concern would lessen if only a few contaminants were accumulated and/or the magnitude of uptake was small. If only 1 out of 12 was accumulated to levels just above control or reference concentrations, the level of concern would be lower still.

Once a significant potential for bioaccumulation is established, the toxicological importance of the different contaminants must be considered. The potential for unacceptable adverse effects is elevated when toxic contaminants such as mercury, cadmium, and PCBs are accumulated. In contrast, concern

lessens if less toxic compounds such as phthalates are found in the tissues of biota. How does one gauge relative toxicity? One of the better sources of information is the numerous toxicity tests conducted by the USEPA as part of their program to develop Water Quality Criteria (USEPA 1980). Additional guidance for determining the toxicological importance of various environmental contaminants can be found in Peddicord et al. (1986).

One question often asked when reviewing tissue residue data is, "How do interactions among the contaminants (e.g., synergism or antagonism) affect the organism?" All interactions that may (or may not) be occurring are expressed in the acute toxicity data. Therefore, this question is somewhat irrelevant for sediment bioassays. To determine the interactive effects among specific contaminants of concern for a particular marine organism, additional laboratory experiments would have to be conducted.

Summary

A review of the literature has shown that about 3 percent of studies investigating the sublethal effects of chlorinated organic contaminants on marine organisms contain both effects and concomitant tissue residue data.

The residue-effects information that is available (Table 2) can be very useful for interpreting the results of project-specific bioassays. It is believed that they also represent heuristic guidance, not to be confused with pass-fail or threshold criteria. For marine and estuarine organisms with whole body tissue residues of chlorinated organic contaminants at or near steady-state, the level of concern associated with adverse sublethal effects is generally:

LOW for tissue concentrations <0.1 µg/g wet weight
MEDIUM for tissue concentrations 0.1-1.0 µg/g wet weight
HIGH for tissue concentrations >1.0 µg/g wet weight

Although the paucity of residue-effects information hampers contaminant-specific guidance, other evaluative techniques are available for interpreting the biological importance of bioaccumulation. For evaluating potential ecological effects, comparisons to reference values derived either in the laboratory or by consensus agreements can be carried out. To assess the potential

for human health impacts, bioaccumulation results can be compared directly to previously developed numerical guidance for contaminated seafood. Human health effects can also be evaluated indirectly by examining trophic transfer potential of contaminants in the marine food web. Finally, tissue residue information can be evaluated by determining the number of contaminants showing mobility, the magnitude of uptake relative to control and/or reference values, and the toxicological importance of contaminants that are bioaccumulated.

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Table 1

List of Scientific Journals and Data Base Search Services Used To Identify Published Papers

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Journals

Aquatic Toxicology
Archiv fur Hydrobiologie
Archives of Environmental Contamination and Toxicology
Australian Journal of Biological Science
Australian Journal of Marine and Freshwater Research
Australian Journal of Zoology
Biological Bulletin
Bulletin of Environmental Contamination and Toxicology
California Fish and Game
Canadian Journal of Fisheries and Aquatic Sciences
Canadian Journal of Zoology
Chemosphere
Comparative Biochemistry and Physiology
Critical Reviews in Environmental Control
Crustaceana
Developmental Biology
Ecotoxicology and Environmental Safety
Environmental Biology of Fish
Environmental Pollution Series A, B, and C
Environmental Research
Environmental Science and Technology
Environmental Toxicology and Chemistry
Estuaries
Fisheries
Fisheries Bulletin, U.S.
Hydrobiologia
International Review of Invertebrate Reproduction and Development
International Revue der Gesamten Hydrobiologia
Journal Applied Ecology
Journal of Crustacean Biology
Journal of Experimental Biology
Journal of Experimental Zoology
Journal of Fish Biology
Journal of Invertebrate Pathology
Journal of Pesticide Science
Journal of Plankton Research
Journal of Toxicological and Environmental Research
Journal of Water Pollution Control Federation
Journal of Zoology
Limnology and Oceanography
Marine Environmental Research
New York Fish and Game
New Zealand Journal of Marine and Freshwater Research
Oecologia
Oikos

(Continued)

Table 1 (Concluded)

Journals (Concluded)

Pesticide Biochemistry and Physiology
Pesticides Science
Physiological Zoology
The Progressive Fish Culturist
Quarterly Review of Biology
Science
Science of the Total Environment
Transactions, American Fisheries Society
US Environmental Protection Agency's Ecological Research Series
Water, Air and Soil Pollution
Water Pollution, Research and Control
Water Quality International
Water Research
Water Resources Research

Computerized Data Base Searches Services

Biosis
Water Resources Abstract
Aquatic Sciences and Fisheries Abstract
Chemical Abstracts
Life Sciences Collection
Zoological Record
NTIS (National Technical Information Service)
Dissertation Abstracts
Conference Papers Index
Pollution Abstracts

Table 2

Summary of Published Papers on the Biological Effects of Chlorinated Environmental Contaminants on Marine Organisms and Associated Tissue Residues

Parameter	Contaminant	Organism	Exposure Time	Exposure Concentration*	Tissue Concentration**	Biological Effect	Reference
Growth	Kepone	Sheepshead minnow	36 days	0.08-6.60	1-22	Growth inversely related to concentration	Hansen, Goodman, and Wilson 1977
Growth	Kepone	Sheepshead minnow	160 days	0-0.12	0-0.86	No effect on growth	Goodman et al. 1982
				0.39-0.78	1.1-5.0	Reduction in growth	
Growth	Kepone	Blue crab	28 days	0.15 µg/g food	0.069	Reduction in growth	Schimmel et al. 1979
Growth	Kepone	Blue crab	65 days	0.36-2.5 µg/g food	0.38-4.16	No effect on growth, ratio of carapace thickness to width inversely proportional to concentration	Fisher, Bender, and Roberts 1983
Growth	Methoxychlor	Crab	10 days	0.7	0.51	Reduction in growth	Bookout, Costlow, and Monroe 1976
Growth	Endrin	Sheepshead minnows	22 weeks	0-1.31	0.94	No effect on growth	Hansen, Schimmel, and Forester 1977
Behavior	Toxaphene	Killifish (embryo)	28 days	ND†-0.6	No data	Reduction in survival at all concentrations	Schimmel, Patrick, and Forester 1977
				1.3-6.5	No data	Erratic swimming, loss of equilibrium	
		Killifish (fry)	28 days	ND-0.6	ND-8.0	Reduction in survival at all concentrations	
				1.3-6.5	34-no data	Reduction in survival at all behavior, loss of equilibrium	
		Killifish (juvenile)	28 days	ND-0.8	ND-24.7	Reduction in survival at all concentrations	
				1.7-3.4	102-no data	Erratic swimming, loss of equilibrium	

(Continued)

* Exposure concentrations are expressed in units of micrograms per litre (µg/ℓ) unless noted otherwise.
** Tissue concentrations are expressed in units of micrograms per gram (µg/g) wet weight whole animals unless noted otherwise.
† ND - Nondetectable, <0.2 µg/ℓ in water, <0.2 µg/g in tissue.

Table 2 (Continued)

Parameter	Contaminant	Organism	Exposure Time	Exposure Concentration	Tissue Concentration	Biological Effect	Reference
		Killifish (adults)	28 days	ND-0.9	ND-6.1	Reduction in survival	
				1.7-3.8	No data	Erratic swimming, loss of equilibrium	
Behavior	Kepone	Sheepshead minnow	28 days	0-1.9	0.26-11	Erratic swimming behavior and a reduction in feeding rate both increased as concentrations increased	Hansen, Goodman, and Wilson 1977
Behavior	Kepone	Blue crab	65 days	0.36-1.64 µg/g food	0.38-1.73	No effect on behavior	Fisher, Bender, and Roberts 1983
				2.26-2.50 µg/g food	2.54-4.61	Excitable behavior during feeding, reduced ability to locate and consume food	
Behavior	Methoxychlor	Crab	15 days	1.8-32	0.11-1.59	Hyperactivity, inability to maintain an upright position, difficulty in locating and coinsuming food	Armstrong et al. 1976
Behavior	Mirex	Grass shrimp	14-16 days	0.011-0.130	0.02-0.20	Diminished ability to avoid predation	Tagatz 1976
Behavior	Mirex	Oyster	10 weeks	0.038	1.3-28	Diminished ability to withstand predation	Tagatz et al. 1976
		Mussel	10 weeks	0.038	1.6-2.0	Diminished ability to withstand predation	
Behavior	PCB DDT	Fish	Field collected	No data	110 7	Decreased ability to maintain position while swimming in a current	Olofsson and Lindahl 1979
Reproduction	Kepone	Sheepshead minnow	90-133 days	0.041-0.074	0.15-0.56	Increased number of eggs/female/day; fertility unaffected	Goodman et al. 1982
				0.12-0.39	0.86-3.0	Number of eggs/female/day unaffected; fertility unaffected	
				0.78	5.0-6.8	Decreased number of eggs/female/day, reduced fertility	
Reproduction	Kepone	Sheepshead minnow	28 days	0.05-0.80	0.26-4.7	Production of normal embryos	Hansen, Goodman, and Wilson 1977
				1.9	11	Production of abnormal embryos	

(Continued)

(Sheet 2 of 5)

Table 2 (Continued)

Parameter	Contaminant	Organism	Exposure Time	Exposure Concentration	Tissue Concentration	Biological Effect	Reference
Reproduction	PCB (Aroclor 1254)	Cod	5-1/2 months	1-50 µg/g wet food	0.06-5.3 (testes)	Disruption in production of sex steroids from testes	Freeman, Sangalang, and Flemming 1982
Reproduction	PCB (Aroclor 1254)	Sheepshead minnow	4 weeks	0-10.0	0.52-170	No effect on number of eggs fertilized	Hansen, Schimmel, and Forester 1973
Reproduction	PCB (Aroclor 1016)	Sheepshead minnow	29 days	1-10	5.4-110 (adults) 4.2-66 (eggs)	No effect on egg fertility, hatching, or subsequent survival of progeny	Hansen, Schimmel, and Forester 1975
				32	200-1,100 (adults)	100 percent mortality in adults	
Reproduction	Endrin	Sheepshead minnow	23 weeks, 1 generation	0.027-0.12	0.20-1.0 (adults) 0.09-0.87 (eggs)	No effect on reproduction	Hansen, Schimmel, and Forester 1977
				0.31	0.94 (adults) 1.80 (eggs)	Reducted fertilization and early hatching, high mortalities	
				0.72	No data		
Reproduction	PCB	Flounder	Field collected	No data	5.0-317 ng/g (ovaries)	Reduced viable hatch at PCB tissue concentrations above 120 ng/g	Von Westernhagen et al. 1981
	DDD				3.0-30.3 ng/g (ovaries)	Hatch viability not correlated with tissue concentration of any other contaminant	
	DDE				0.1-62.0 (ovaries)		
	Hexachlorobenzene				0.06-2.0 (ovaries)		
	Dieldrin				0.1-49.0 (ovaries)		
	Heptachlorepoxide				0.08-3.0 (ovaries)		
Reproduction	PCB	Fish	Field collected	No data	19-241 ng/g (ovaries)	Reduced viable hatch at PCB tissue concentrations above 18 ng/g	Hansen, Von Westernhagen, and Rosenthal 1985
	DDD				<1-16.0 (ovaries)	Hatch viability not correlated with tissue concentration of any other contaminant	
	DDE				<1-34.0 (ovaries)		
	Dieldrin				<1-8.1 (ovaries)		
	Hexachlorobenzene				<1-8.6 (ovaries)		
	Heptachlorepoxide				<1-8.9 (ovaries)		

(Continued)

Table 2 (Continued)

Parameter	Contaminant	Organism	Exposure Time	Exposure Concentration	Tissue Concentration	Biological Effect	Reference
	α Hexachlorocyclohexane γ Hexachlorocyclohexane				<1-9.2 (ovaries) <1-12.1 (ovaries)		
Morphology	PCB (Aroclor 1254)	Cod	5-1/2 months	1-50 µg/g wet food	0.04-2.1 (kidney) 0.02-0.98 (muscle) 10.1-374 (liver)	Disruption in production of adrenal hormones from kidney No effect on histopathology of kidney Degeneration of liver's fatty tissue	Freeman, Sangalang, and Flemming 1982
Morphology	PCB (Aroclor 1254)	Cod	5-1/2 months	1-50 µg/g food	0.06-5.3 (testes)	Response intensified as tissue concentration increased and progressed from testicular fibrosis to inhibition of spermatogenesis and finally to complete disintegration of the testes	Sangalang, Freeman, and Crowell 1981
Morphology	PCB (Aroclor 1254)	Cod	5-1/2 months	1-50 µg/g wet food	0.02-0.98 (muscle)	Hyperplasia of gills with disrupted blood spaces	Freeman, Sangalang, and Flemming 1982
Morphology	PCB (Aroclor 1254)	Shrimp	35 days	0.6-0.7	2 (muscle) 21 (hepatopancreas)	Increased occurrence of viral pathogen	Couch and Courtney 1977
Morphology	Kepone	Crab	65 days	0.36-2.50 µg/g food	0.38-4.61	Carapace thickness-to-width ratio inversely related to concentration	Fisher, Bender, and Roberts 1983
Morphology	Kepone	Killifish	28 days	0-1.9	0.26-11	Response intensified as tissue concentration increased. Response progressed from deformed vertebral column, hemorrhaging near brain, and darkened posterior to increased hemorrhaging and fin rot	Hansen, Goodman, and Wilson 1977
Morphology	Dieldrin	Oyster	43 days	1-100	25.6-2,685*	No effect on fibrous or cellular components of gills, gut, or mantle, no inflammation or infiltration of leucocytes	Emanuelsen, Lincer, and Rifkin 1978

(Continued)

* Data originally reported on a dry-weight basis were converted to wet weight assuming 80 percent body water.

Table 2 (Concluded)

Parameter	Contaminant	Organism	Exposure Time	Exposure Concentration	Tissue Concentration	Biological Effect	Reference
Osmoregulation	Pentachlorophenol	Fish	5 days	100	37.1	Reduction in total osmotic pressure	Thomas, Carr, and Neff 1981
Osmoregulation	Methoxychlor	Crab	7 days	10	0.31 2.0 (gill)	No effect on total osmotic pressure	Caldwell 1974
		Crab	14 days	10	1.0 2.5 (gill)	No effect on total osmotic pressure, sodium or potassium regulation but magnesium regulation was disrupted	
Osmoregulation	DDT	Crab	50 hr	Single injection of 100 µg/kg	0.06 (gill) 1.5 (hepatopancreas)	Sodium and potassium regulation in the gill disrupted	Neufeld and Pritchard 1979
Metabolism	PCB (Aroclor 1016)	Horseshoe crab	96 days	0.35-71.5	0.08-92.8	No ecologically significant change in oxygen consumption	Neff and Giam 1977
Metabolism	Halowax 1099 (chlorinated naphthalene)	Horseshoe crab	96 days	22-70	0.51-5.7	Highly variable oxygen consumption	Neff and Giam 1977
Metabolism	Kepone	Blue crab	65 days	0.36-1.64 µg/g food	0.38-1.73	No effect on oxygen consumption	Fisher, Bender, and Roberts 1983
				2.26-2.50 µg/g food	2.54	Elevated rates of oxygen consumption	